

IOP Conference Series: Materials Science and Engineering

PAPER • **OPEN ACCESS**

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To cite this article: M Mohammed *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1092** 012049

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Eco-Ontology for supporting Interoperability in Product Life Cycle within Product Sustainability

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Abstract. Ontology originated in a branch of artificial intelligence and widely used in various fields such as semantic web, engineering systems, software engineering, biomedical informatics, library science, information engineering, knowledge management, decision-making system, and the industry sector. Ontology supports the knowledge management system and helps get significant features of product design. The lack of using knowledge is the critical challenge in information interoperability of the manufacture, especially, in the early stage of design. This information must be gathered, stored, shared, reused, and managed in a consistent and standardized way. The aim of this study is to use the ontology for reducing the complexity of information and increasing its organization, facilitating sharing and reusing of information, and improving its accuracy. The use of ontology has shown optimistic results to support comprehensive decisions in the industrial field. The researchers have confirmed the importance of using the ontology to improve interoperability over the product life cycle and address the impacts of products through the outputs of the product life cycle assessment tool. This study is expected to contribute to develop an efficient and practicable sustainability tool during product design with a complete view to solve the lack of sharing information in the product life cycle, provide high quality and comprehensive recommendations to support the manufacturing processes for product sustainability.

Keywords: environment sustainability, eco-design, life cycle assessment, ontology, product design

1. Introduction

Sustainability is the optimal use of natural resources according to the environmental perspective to meet current human needs while preserving the needs of the future generation [1, 2]. Sustainable product development is accomplished by integrating the three dimension of sustainability which are economic, social, and environmental aspect, as shown in Fig. 1.; these dimensions have become essential to product innovations that protect environment and public health over their whole life cycle, from extraction of raw materials to end of life [3]. Sustainability assessment has received attention from researchers and provides opportunities to measure and evaluate the achievement of sustainability [5]. Eco-design is an approach for products design with important consideration for the economic, environmental, and social effects of a product over their whole life cycle, improving the efficiency of eco-design is a major challenge in sustainable development in product design [6, 7]. Life Cycle Assessment (LCA) is a good tool to analyze and assess the impacts of environment of a product through all product's life cycle stages from raw material selection through process of materials, manufacture, transportation, usage, maintenance, and end of life strategies in the whole product life cycle [9–12]. Life Cycle Cost (LCC) is used for economic evaluation [13].

Social Life Cycle Assessment (SLCA) is focused with assessing social impacts [14–16]. Life Cycle Sustainable Assessment (LCSA) is a mix of all three aspects of LCA, LCC and SLCA sustainability [3, 10, 17]. Different tools and methods have been developed for products sustainability, but they still critical application of the eco-design process, social impacts, and economic cost and lack critical knowledge of



environmental costs and production throughout the early stages of design, current research confirm that knowledge offers a way to deal with the knowledge of domain effectively and practically [11, 18–20]. Ontology is an explicit specifications of conceptualizations and an official explanation of knowledge as a set of concepts in the domain and the relation that link them by formally specify components [5, 21]. The ontology offers a decision-making supporting tool through eases evaluating the environmental performance [22]. In the field of industry, ontology facilitates the use of economic, environmental, and social assessment methods, the sharing and reusing the relevant information of product [23], and supports design able to extract features to represent the manufacturing process lines and machines [24]. Ontology enables process selection by determining the competitive match between product features, material properties, and process capabilities through the application of automatic inferencing and similarity retrieval, this paper is organized as follows. Section 2 gives a principle of product sustainability. Section 3 introduces the ontology engineering and the process of development and evaluation. Section 4 presents the eco-design approaches. Section 5 presents the eco-design based on ontology for product sustainability. Section 6 specifies the information interoperability, followed by conclusions in Section 7.

2. Product Sustainability

Sustainable product designing is a product design process taking into account environmental, economic and social sustainability via the entire product life cycle [3, 12, 23]. The implementation of sustainability considerations should be implemented at the earliest possible stage of designing product to create a more sustainable green product and selects the best way for meeting the needs of consumers in a sustainable method [24–27]. Sustainability assessment has received attention from researchers and has provided opportunities to measure and evaluate sustainability achievement [5]. Previous product design actions usually focus on achieving high profit through high quality and low cost, while environmental issues are often not combined with current activities in traditional procedures of product design, and the more severe environmental requirements constantly lead to additional constraints and costs [28, 29]. One of the major challenges for any manufacturer is to include sustainable development aspects in the design of product related to three dimensions which are economic, environmental, and social impacts throughout their entire life cycle, from extracting raw materials to final disposal. LCA is used to assess the environment impacts, LCC is used to assess economic impacts, and S-LCA is used to assess the social impacts. Meanwhile, LCSA is a methodology to merge the LCA, LCC, and S-LCA that aim of optimization for providing a comprehensive vision of product sustainability [25] and supporting decision makers in the design stage to develop more sustainable products [17]. The critical challenges is the lack of using knowledge in sustainability assessment in the product life cycle start from designing, raw materials selection, production, transportation, usage, and end of life plans [9–12, 30]. Designing phase plays an increasingly important role in the product sustainability [3, 30–31]. So the needs of customer must be understand and incorporating them into the early stages of product design is critical to the product design [32], [29], inference and knowledge base are applied because design goals cannot be created automatically using any methods or tools at this time [25]. Selection materials process plays an important role in determining the impacts of environmental and uses in different eco-design approaches [31, 32, 21]. Manufacturing processes are stages start with collect the raw materials and end with final products [18]. Transportation is very important phase in product life cycle, where local consumption of the products is a key factor for sustainable environment and the short way is significant for the environmental, economic, and social sustainability [6]. The usage phase depends on the consumers and the benefits that accrue to them, some important things like product attributes, product use conditions, product quality, product efficiency, and product price [25]. End of life strategies reduce environmental impacts related with raw material extraction and waste action at the end of life by disposed by landfill or incineration or reusing, remanufacturing, and recycling [35], which has activities with time ranges, and these ranges can vary significantly, an activity like waste disposal can take short time, whereas the resulting emissions continuous for several years [36]. The most important for product sustainability is the reusing and sharing of information during the design phase [33, 35], with possible design solutions related to goals and constraints design [20] which related to assess all effects during the others product life cycle phases, especially the stages with a major impact such as material selection [33], [34], transportation [6], and end of life [36, 37].

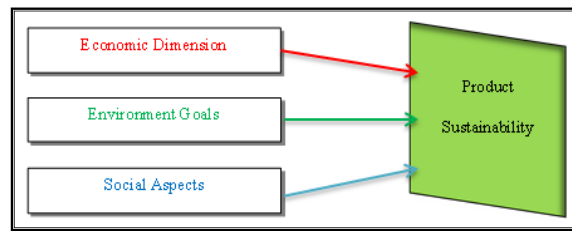


Figure 1. Sustainability dimensions diagram

3. Ontology Engineering

Ontology originated in a branch of artificial intelligence for systems which based on knowledge and developed to the problems of retrieve information [48, 49]. Ontology is widely used in various fields such as artificial intelligence, semantic web [28], engineering systems [41], software engineering [42], biomedical informatics [20, 53], library science [19], information engineering [40], knowledge management [29], decision-making system [44], and industry sector [24], the reason for this is that ontology reduces the complexity of information and increases its organization [45] and facilitates the sharing of information [40]. In the field of industry in addition to the above, it is also facilitates the use of economic, environmental, and social assessment methods, easy for reusing the relevant information of product [23], and finally support structure design able to extract features to represent the manufacturing process lines and machines [24].

3.1 Ontology Engineering Languages

Ontology language is an official language used to encode ontology and user can write clear official representations of domains models, there are five main requirements that the ontology must provide: it must be clear structure, clear semantics, effective reasoning support, expressive strength, and lastly, comfortable for expression [57, 58]. There are many languages for ontology: Resource Description Framework (RDF) [48], RDF Schema (RDFS) [40], Ontology Web Language OWL [49].

3.2 Ontology Engineering Tools

Ontology tools are applications designed to help for creating or manipulating ontology. There are many tools that express ontology, in the following subsections; some of these tools are explained:

Protégé [50] is a Java-based tool that developed by the Stanford University for creating domain models and knowledge base applications using ontology. It is free open source ontology development platform that enables users for dealing with RDF, OWL, and Frame-based ontology and support the construction, visualization and dealing of ontology in several forms of representation. Protégé manage the description of classes, sub-classes, properties, data properties, constraints, and the relations between classes and the properties of these relations. Protégé allows building knowledge base tools and applications through Java-based application programming interface (API) and plug-in.

TopBraid [51] is a tool for industry experts for the creation, maintenance, and management of RDF, RDFS, and OWL ontology in semantic web. TopBraid is a knowledge base model and ontology editor that offers graphic editing support, also compatibility with databases and XML. Topbraid is depends on Jena API and Eclipse platform. Logical rule-based engines are integrated simply in TopBraid. OWL Inference engine is used to test, consistence check, and debug, while, SPARQL query engine is used to retrieve data.

OntoStudio [52] is a knowledge base model and ontology environment that supports for developing and maintaining ontology by graphical methods. OntoStudio is based on IBM Eclipse framework. The ontology is managed depends on the client/server architecture and different clients can access and update this ontology. Cooperative development is supported, the concepts and properties hierarchy can be create and update by user.

3.3 Ontology Developing Stages

There are three main stages of ontology development [53]: the early stages, the intermediate stages, and the later stages. The early stages of the process focus on planning, gathering of concept, modeling, and identify the tools for planning and modeling. In the middle stages of the process, the techniques of design ontology is used to design the ontology base, user interface, and define specifications of ontology languages such as RDF and OWL. Later stages are the design and implementation of rules for inquiries about ontology and mapping ontology in tree listings.

3.4 Ontology Evaluation Stages

Ontology evaluation is concerned with measuring the correctness and quality of ontology. ontology validation is to analyze that the ontology is conform to ontology modeling best achieves and check is the ontology does not contain pitfalls or anomalies [59, 60]. There are errors that appear during the evaluation of various advantages such as consistency, completeness and accuracy in ontology taxonomies, there are also tools to warn the most common pitfalls appearing within ontology developments such as: The relationship domain or range is defined as the intersection of two or more classes, this warning can avoid the problems of inference if these classes are unable to share instances; The maintainability, accessibility, and clarity of ontology can be enhanced when the naming convention is not used in ontology elements; Modeling and reasoning problems can be avoided by include a cycle between two classes in the ontology hierarchy [61, 62].

4. Eco-Design

Currently, eco-design for products sustainability which is a comprehensive concept of product design and development is receiving more and more attention. Eco-design is a strategies system that goal for balancing and integrating of economic, environmental, and social aspects during its whole life cycle in product design phase [12, 33]. Eco-design strategies plays an important role in decreasing economic, environment impacts [58], and social impacts [35], especially in raw material selection [21, 32], transportation stage [6], and end of life strategy [7, 37]. Most of the current eco-design approach has focused on environmental and economic aspects of product sustainability [3, 5]. Recently, social aspects has been added to product sustainability where social life cycle assessment offers a new high-efficiency method of product life cycle assessment particularly in design stage [41]. The efficiency of sustainability assessment depends on the available knowledge to enable semantic interoperation between product properties and eco-design parameters [12, 26]. A new tool which is ontology is emerging to account for other dimensions of sustainability along with the improvements in the existing eco-design tools that researchers classified it to main categories which are: checklist based [23], life cycle assessment [16], quality function deployment [3], case based reasoning [7], as shown in Table 1.

Table 1. Comparison of Eco-Design Tools.

Criteria / Eco-Design Tool	Checklist	QFD	LCA	CBR	Ontology
Early Design Phase	✓	✓	✓	✓	✓
Store Detailed Information			✓	✓	✓
Reuse Data		✓	✓	✓	✓
Share Information				✓	✓
Semantic Interoperability					✓
Automatic Reasoning					✓
Complex Knowledge					✓

Table 1 explains the comparison of eco-design tools regarding to the categories above, where Checklist consists of different questions related to the sustainability aspects; it is suitable to examine design options in early stage of designing the sustainable product. Checklists limitations are that it provides a very simple

representation that can conduct to unclear results. It can not offer the detailed information needed for analysing. Also, they cannot possible to take advantage and reuse of the current results and data for future products because there is no documentation of procedures for obtaining specific results the sustainability. Checklists do not enable semantic interoperability, automatic reasoning, and complex knowledge. LCA is a scientific approach to for integrating environmental sustainability standards into design and evaluating related products, services and procedures, however, it does not offer guidance on how to achieve the improvements and lacks the requisite level of interactivity for supporting design experts for plans of enhancement. It does not enable semantic interoperability, automatic reasoning, and complex knowledge. QFD is a tool which focuses on customer requirements understanding, it used in the first stage which is the product designing stage by interpreting the customer ambitions to meet the customers' needs to produce a set of properties. QFD can not offer the detailed information needed for analysing the sustainability. It does not enable information sharing, semantic interoperability, automatic reasoning, and complex knowledge. CBR is a tool developes for searching and reusing the similar cases from their historical experiences in database, CBR tools have been developed to contain sustainability aspects but not in an integrated approach and inferencing based on similarity only and not automatically generated for details design which can be the basis of enhancing plans. It does not enable semantic interoperability, automatic reasoning, and complex knowledge.

For the limitation of the existing researches, the integration of environmental, economic, and social aspects at the design phase is required. The integration will help the collaboration between designers and consumers, and it will permit designers to create new innovations for designing sustainable products and environmentally friendly. To fill this gap, ontology can be used to assess all three dimensions of sustainability and integrated them to facilitate the sharing and reusing knowledge for products sustainability.

5. Eco-Design Ontology

Ontology is a tool to represent knowledge, one of the key reasons for the current increasing importance in ontology is the development of the management of knowledge on an international scale, ontology has historically been applied to many research area strongly [33]. Previous product design actions usually focus on achieving high profit through high quality and low cost, while environmental issues are often not combined with current activities in traditional procedures of product design, and the more severe environmental requirements constantly lead to additional constraints and costs [35, 64]. The researchers focused on the use of ontology in several areas such as classification process which uses ontology in application systems [43], manufacturing modeling which contains product modeling, process modeling, resources modeling [59, product life cycle process [21], and sustainability assessment process [60]. Product life cycle process contains design process ontology, production process ontology, transportation process ontology, testing process ontology, maintenance process ontology, and end of life process ontology [21], the most important of which is the reusing and sharing of information during the design phase [31, 40], with possible design solutions related to goals and constraints design which related to assess all effects during the others product life cycle phases [20], especially the stages with a major impact such as material selection, transportation, and end of life, so researchers generally focused on the product life cycle and in particular on detailed stages such as material [29, 30], transportation [6], and end of life [23, 34].

Table 2. Ontologies development in sustainability assessment

Authors	Design	PLCO	LCAO	LCCO	S-LCAO
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[2]	✓		✓	✓
[20]	✓	✓		
[22]	✓		✓	✓
[35]	✓		✓	
[41]	✓			✓
[42]	✓	✓		

Sustainability assessment process identifies sets of various ontology of product sustainability assessment such as life cycle assessment ontology [2, 5, 32, 33], life cycle cost [35, 67, 68], and social life cycle assessment ontology [3, 28, 36, 69]. Table 2 shows a comparison of the relevant ontologies of eco-design product sustainability. Since 2002, related works to the development of ontology has been applied to knowledge of PLC, LCA, LCC and S-LCA. Analysis of the literature enables the identification of a range of different approaches to sustainable assessment. Mostly, they emphasize three dimensions of sustainability: environmental, economic and social. They can be classified into several groups, i.e., Product Life Cycle Ontology (PLCO) [20, 42], Life Cycle Assessment Ontology (LCAO) [2, 35], Life Cycle Cost Ontology (LCCO) [2, 22], and Social Life Cycle Assessment Ontology (S-LCAO) [41]. Table 2 shows the need of knowledge for interoperability for reducing the complexity of information and increasing its organization, facilitating sharing and reusing of information, and improving its accuracy. Ontology can enhance sustainability performance in manufacturing, to decrease the environment, economic, and society impact through available indicators to the decision makers. Decision-making system uses the ontology for formalizing and organizing the information [44]. The use of ontology has shown optimistic results to support comprehensive decisions in industrial section, for example expected maintenance, environmental assessment, diagnosis and forecasting, and estimated cost [18].

6. Information Interoperability

There are several approaches and tools for developing the products sustainability, but the lack of using knowledge is the critical challenges in interoperability of the Life cycle sustainable assessment during conceptual design in the product life cycle that starts with the selection of raw materials, manufacturing process, product usage, transportation, and ends with end of life strategies. Through querying and interoperability the ontology can play a key role in intelligent manufacturing [63]. Eco-Ontology tool can be used to meet the requirement of the data storage and interoperability in the Life cycle sustainable assessment. The result from the assessment in the Life cycle sustainable assessment process can be reused and retrieved in a simple way. Eco-Ontology will help product designers to use quantitative metrics to discover alternative materials for product design and manufacturing processes throughout interoperability of product life cycle stages multiple for achieving wanted flexibility to assess the product sustainability. Decision-making system uses the ontology for formalizing and organizing the information [64]. Ontology can enhance sustainability performance in manufacturing, to decrease the environment, economic, and society impact through available indicators to the decision makers. The use of ontology has shown optimistic results to support comprehensive decisions in industrial section, for example expected maintenance, environmental assessment, diagnosis and forecasting, and estimated cost [18]. The ontology offers a supportive tool for decision-making by merging dissimilar information systems, which adjusts and identifies the dissimilar elements to enable assessing the performance of environmental, incorporating environmental topics into the semantic representation that increases the managing of existing data and produce quality information to enhance decision-making [22]. Using ontology for improving decision support in sustainable manufacturing [18]. Existing LCA ontology were constructed for simulation and decision support systems [2]. Decision-maker's environment can play a role in defining decision-making to solve the environmental complexity through the integration between eco-design and ontology that will produce the high quality recommendations for decision makers accurately and in required time [56, 57].

Ontology forms the basic structure for data organization and supporting decision making applications by designing a knowledge-based system, by simulating a sustainable industrial expert who can find opportunities for mechanical change and suggest alternatives based on the current production setting and can then be implemented to future designs to improve the product.

7. Conclusions

The article discussed the history and the important role of using ontology in eco-design and usefulness of using ontology to formalize and share data in the manufacturing environment. Ontology can be used to solve the problems that limit competition between manufacturers, such as supporting dynamic and rapid industrial change, interoperability of multiple domains, and reducing the cost of product development according to environmental standards by reusing existing ontology. The integration between ontology and life cycle sustainable assessment will play a key role as methodology during design phase for supporting the decision-making process for sustainable product. In this paper the main aims are to make good use of the ontology for the LCSA information for achieving better accessibility, comparability and quality assurance of information used in the products LCSA and to integrate the LCSA aspects in the design process for the development of the product, whereas, the search for the life cycle sustainable assessment remains open research.

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Acknowledgment

The research reported in this study is conducted by the researchers at University Malaysia Pahang (UMP), it is funded by FRGS/1/2018/TK10/UMP/02/3 grant. The researchers would like to thank Ministry of Higher Education and UMP for supporting this research.